

THE U.S. DEPARTMENT OF ENERGY (DOE)—ADVANCED
TURBINE SYSTEMS (ATS) PROGRAM

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I am representing DOE for Morgantown West Virginia. And we are also partnering with the Office of Energy Efficiency Renewable Energy and they are looking at the industrial scale engine as well as fossil energy and they are working at the utility scale. We define industrial scale as being approximately 5 to 15 megawatts and our utility scale is over 200 megawatts so these are large scale power generation. The program started as a result of the Energy Policy Act of 1992, and we are currently now in Phase III. What I want to talk to you about was what the program consists of and where we are today. You'll be hearing speakers representing General Electric, Westinghouse, Allison, but I don't think Solar Turbines is represented here today. The goals of the program in the year 2000 and this is firing on natural gas fuels - is for us to have a high efficiency gas turbine based system for utility markets. And by high efficiency in the utility markets, we are looking at upwards of 60% efficiency. So we are getting up there to that hurdle of the 60% in overall efficiency. We are looking at single digit NO_x without the SCR (selective catalytic reduction) and by single digit we're talking as low as 1 or 2 ppm where we are looking at catalytic combustion. And we also have some of our vendors who are looking at other proven NO_x technology. And they're at 8ppm NO_x emissions. Fuels flexibility right now is concentrating on natural gas. That will be the demonstrated fuel and that looks like the near term fuel to use. However, we have a small test going on with the participants where they are looking at biomass and gasification, that is coal derived gas. Pressurized fluid bed combustion smaller scale biomass gasification. We want the costs of electricity to be 10% lower than it currently is today at the buss bar and the inlet temperature of 2600 F. And if ordered to achieve the high efficiencies, the key objective is increasing these turbine rotor inlet temperatures. And so far we have been very successful and are well on our way to a successful demonstration. The participants in the program have narrowed down over time - we started out with a large number of participants in Phase I and then we went to concept development and we are wrapping that up. That was approximately a two year effort. GE and Westinghouse have been participating on the utility scale: GE on the intermediate engine development as well, approximately 130 megawatts in the cycle. Solar and Allison are participating in the industrial scale engine development and we have ABB come in later on in the utility scale and they'll be working through Phase II and Phase III overlap. And we are currently in Phase III. The awards were made in September of 1995. That is a two year period - we are going to wrap up by the summer of 1997. And we have some previous participants, and the only one not participating in Phase III is ABB. Again Allison and Solar - industrial scale engines, Allison being the aero-derivative technology and GE and Westinghouse on the utility scale. We will then move these participants into Phase IV which is the demonstration of the actual technology and we feel very certain that we are going to have utility or industrial participants in these demonstrations. Phase III technology testing is actually improving the technology and we'll get into that later - and have some very promising results.

These are the two phases that I talked about before - comparing phase III and phase IV after the year 2000. So we have our advanced technology demonstrated at that stage. Also looking at key areas of materials and aerodynamics and heat transfer. Now we are looking at that with some cooperative investigations in ceramics and advanced alloys with OakRidge National Laboratory. They are working with our participants; we'll also have quite a large academic consortium. We have several partners going on now - we will be working with industry on research related topics at universities across the country. And we have also at the Federal Energy Technology Center, Inhouse research, heat transfer, and we have a large combustion laboratory. But we don't do full scale testing but we do have subscale testing going on there. And we have had quite a bit of success with heat load and combustion technology. We are also carrying through coal applications and biomass applications, development program to supplement what is going with the vendors and their technology development program. So as I said, we are now in phase III and IV, I've covered most of these goals. And I will carry through and discuss with you what some of the technologies we are looking at in order to reach those goals. On the utility systems, this is the combined cycle configuration that is the generic configuration defined by General Electric and Westinghouse. And where we are really focusing on is compressor technology, combustor technology and gas turbine. They are focusing on areas of materials, thermal coatings, steam compatibility with materials. We are looking at full pressure testing with combustion technology, dry low NO_x, catalytic combustion. Aircraft derivative compressors, for example General Electric - they were looking at an aircraft engine scale up compressor and they were looking at diffuser designs for efficient pressure recovery into the turbine inlet.

On the industrial scale program, air intercooling and recouperation, Gary Holloway will be following up with this, representing General Electric. They have done some work on intercooling and the intermediate engine. Recouperation is an aspect of the Solar Turbine technology. We are also looking at a lot of the same activities like combustion technology as well as utility scale engines. And we are also looking at alternate materials, high strength alloys, TBCs, with the power turbine, specifically Solar Turbines is looking at vanes and blades of ceramic materials to reduce the cooling airflow. So that is a prime area that they are focusing on is high strength ceramics. Just to add a little bit of color - here is a photograph that General Electric provides me. This is the high light of testing that was done - full pressure recovery in the advanced turbine system. Also General Electric has provided me with a nice photograph of the liquid crystals thermography with the heat transfer co-efficient which is being employed on the blades and vane platforms. This is just a very small portion of all the activity that is going on in the program helping to increase engine efficiency. Westinghouse has provided us with a nice schematic of their advanced turbine. They have a lot of similar components as General Electric does of their compressor/pressure ratio's a little bit higher - the GE one is 23-1 --- aircraft engine throughout the cycle. As usual they have a four stage turbine - GE has added stages to their turbine when they developed the H technology from 3 to 4. But what is most important is that we are approaching 2600 degrees-F turbine inlet temperature. This is a hurdle which has never been achieved before in these utility turbine systems.

Now what I would like to do is to give you a feel for what is going on with Westinghouse, specifically now in phase III.

Some of the areas they are looking at are validations. They have done some conceptual designs and selection on thermal barrier coatings and sealing technology and blade design. They are now going through a full scale testing to validated design system. Some of the areas they are looking at are rotor and air sealing development. Active tip clearance control systems and GE and Westinghouse are installing active control systems on their engines and that is another method to increase the efficiency of the engine aside from the sealing and higher temperatures. The next closed loop cooling development that is key to increasing the efficiency of the engine and also by increasing the efficiency of the whole cycle itself which is combined cycle system to 60% efficiency is not cooling the first stage nozzle or blade with air anymore but to use steam. Once the steam is utilized that allows you to have less of a temperature gradient across that nozzle at the entrance of the blade of the turbine ;you have higher turbine temperature; then when you have air flow cooling. It also allows less disturbance of the air flow on the airfoil. By doing that we are addressing materials concerns by introducing steam as a cooling fluid. GE and Westinghouse are both addressing materials steam interaction issues on rotor blades steam glands, rotor, blades, etc. As I said before the vendors are looking quite a bit at some thermal barrier coating integrity issues, stresses, and bond coats assuring that the thermal barrier coating stays on the component and doesn't spall. They are also looking at advanced casting, the first stage, the single crystal and directionally solidified blades for future stages. That increases the strength of the blade and permits higher temperature usage. I will not dwell on this slide because we have a representative from Westinghouse. However when we ask Westinghouse to provide us with some information on what they are looking at though sealing technology and utility scale engines. They provided us with a setup of check list they are actually focusing largely on brush seals there maybe some more activities that are going on that will be discussed today But within our utility scale program they are looking at large seals, they are looking at testing large seals, interference, surface speed etc. They have made some accomplishments, subscale rig testing to assess the design configurations and do further testing in Phase III and should be wrapping up within a year. Moving on to General Electric. This is the H-engine that was announced two years ago in Amsterdam, this is the heart of the advanced combined cycle. To give you a feel for what some of the performance characteristics are I will refer to current technology with General Electric. The 7-H engine is the ATS engine, which has some increase in turbine inlet temperature, increased air flow in the aircraft derivative, higher compressor the pressure ratio, and there will be a guarantee on hydrocarbon and NO_x. Ideally DOE supports domestic engine development, however GE is developing an 50 Hz engine in a parallel program with the DOE support activities.

And where is General Electric Today? They are doing the design work on the engine and doing validation and testing. They are also doing computer integrated system on combined cycles. As I said before the utilities scaled up to be an aircraft engine compressor for heavy duty operation power generation. The dry low NO_x combustor system will be used (2.6) technology and advanced technology for turbine itself so three dimensional aerodynamics is key in evolving performance of the engine. Now this is the one thing that will not be presented today are areas central to sealing and secondary flows. One aspect of sealants that's going on in the General Electric Corporate research division is looking at static seals that is turbine shroud and first stage nozzle in the transition area. (1st stage nozzle segments). It is a CRD invention being tried as a sealant new technology stator-rotor section of the turbine. There has been some testing done on

shim cloth seals and those were tested on the rig they were at pressure but not at high temperature. General Electric has then designed a shoe box test rig for testing the seals at the temperature and operating conditions that is approximately 150 psi differential pressure and 1000 F. Some of the accomplishments that have come up as I've said in Phase II is the metal cloth shim seal that they developed at room temperature rating and the shoe box rig studies done in the higher temperatures case and the cloth seals are now being evaluated underneath the turbine operating conditions. According to General Electric, developed cloth and shim seal to move and seal effectively without failure at pressure and temperature conditions. As I've said before these are the areas where the sealing is being applied and nozzle shroud area and these are the cloth shim seals General Electric provided me with the schematics of the two designs that are evaluated. This is the wrapped design with the cloth wrapped around the shim (cloth amount the shim and clamped). There's also a welded design for front shim. These are two designs that they are looking at and these are some of the results that they are coming up with. So the wrapping techniques are still being evaluated. They are promising new sealing technologies for the turbine which will increase the efficiency of the gas turbine working toward the efficiency goals we have in the program. Another activity that is going on is brush seal development. I believe Chris Wolf is here today and he is working on the brush seal development. So I will just run through this quickly to provide you with some information. The intent of the brush seal development is to replace the labyrinth seals on the steam plant to reduce cost and also to provide better sealant technology. He is doing some testing on the turbine operating conditions and also looking at some steam interactions of materials. Where to go from here? Unfinished Phase IV, 1/2 way through validation and integrated seal technology. Develop mature sealing techniques. GE and Westinghouse are well on their way.

Q. Tony Smally Southwest Research. The industrial turbine is that for mechanical drive or for power generation?

A.. Primarily for power generation although the Allison/Solar is looking at the drive compressor for application to gas lines.

Q I hear about cloth seals - is that used to effectively rotate with or in parallel to what is the principal operation of that?

A. I think static gas path shroud seal is braided.

Q: What is RAM

Ans. Reliability, Availability, Maintainability.

I also want to mention that starting November 6th through the 8th there will be an Advance Gas Turbines Conference with emphasis on ceramics and also we have extra copies of the proceeding - Contact Abbie Layne DOE.

Why the ATS Program is a Major DOE Thrust

- Accelerates Introduction of Improved Power Generation System to U.S. Customers
 - Efficiency benefits
 - Environmental benefits
 - Economic benefits
- Helps the Gas Industry
 - Load leveling in summer-peaking power generation industry helps pay for gas infrastructure development

Why the ATS Program is a Major DOE Thrust (Cont'd)

- Worldwide Environmental Benefits
 - Reduced NOx and CO2 emissions
- Helps U.S. Gas Turbine Industry Maintain World Leadership
 - Keeps a \$2 billion/year business healthy
 - Enhances export market

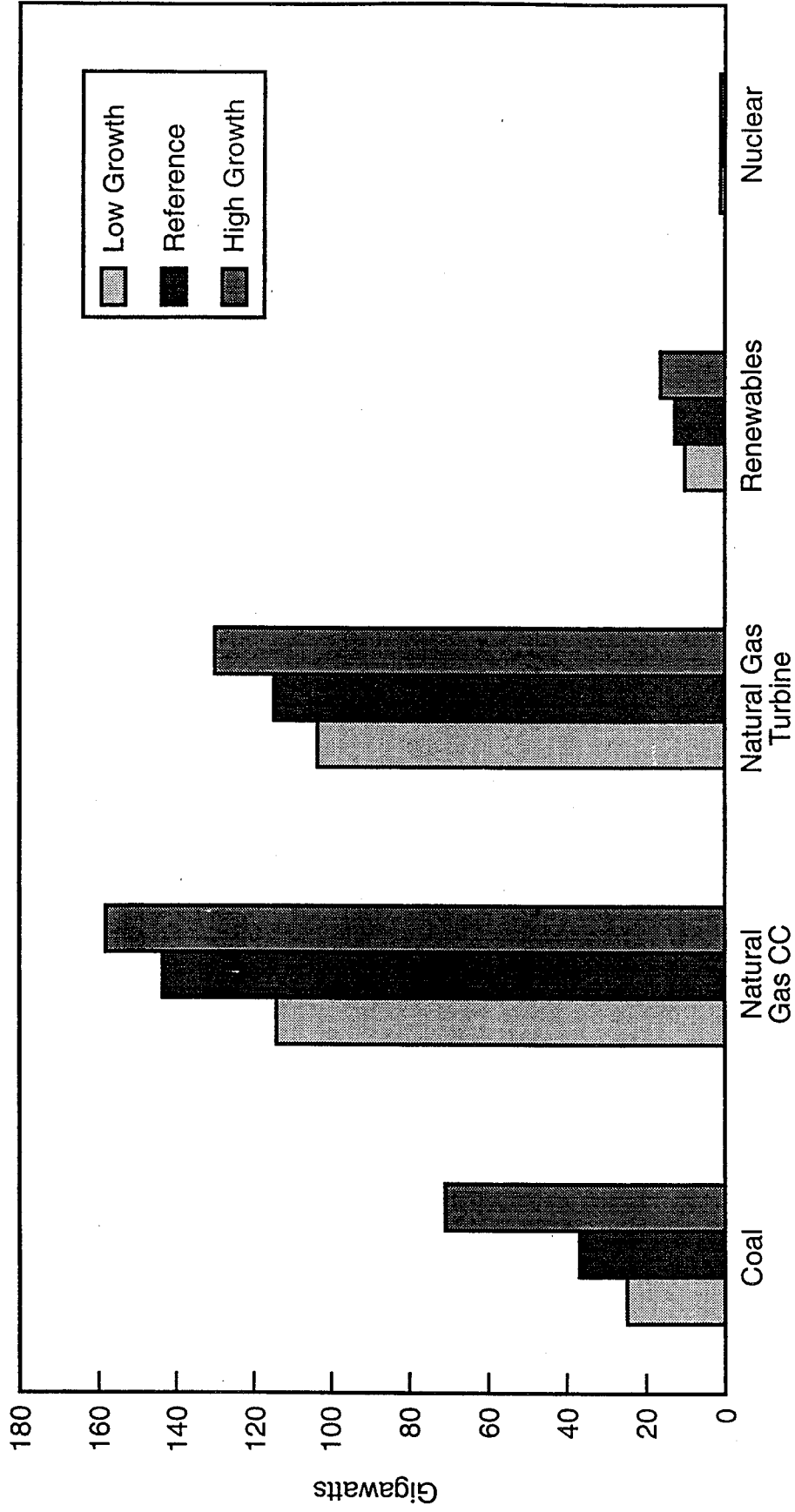
What Are The Program Benefits?

- Cleaner environment
- Lower cost of electricity
- Secure, reliable electric power supply
- Continued use of coal & natural gas. our most plentiful fossil fuel
- Reduced carbon dioxide emissions
- Leadership in power systems & environmental technology
- Stronger power industry, stronger economy, & more jobs

Domestic Drivers

The Potential Need for New Capacity

1995 to 2015



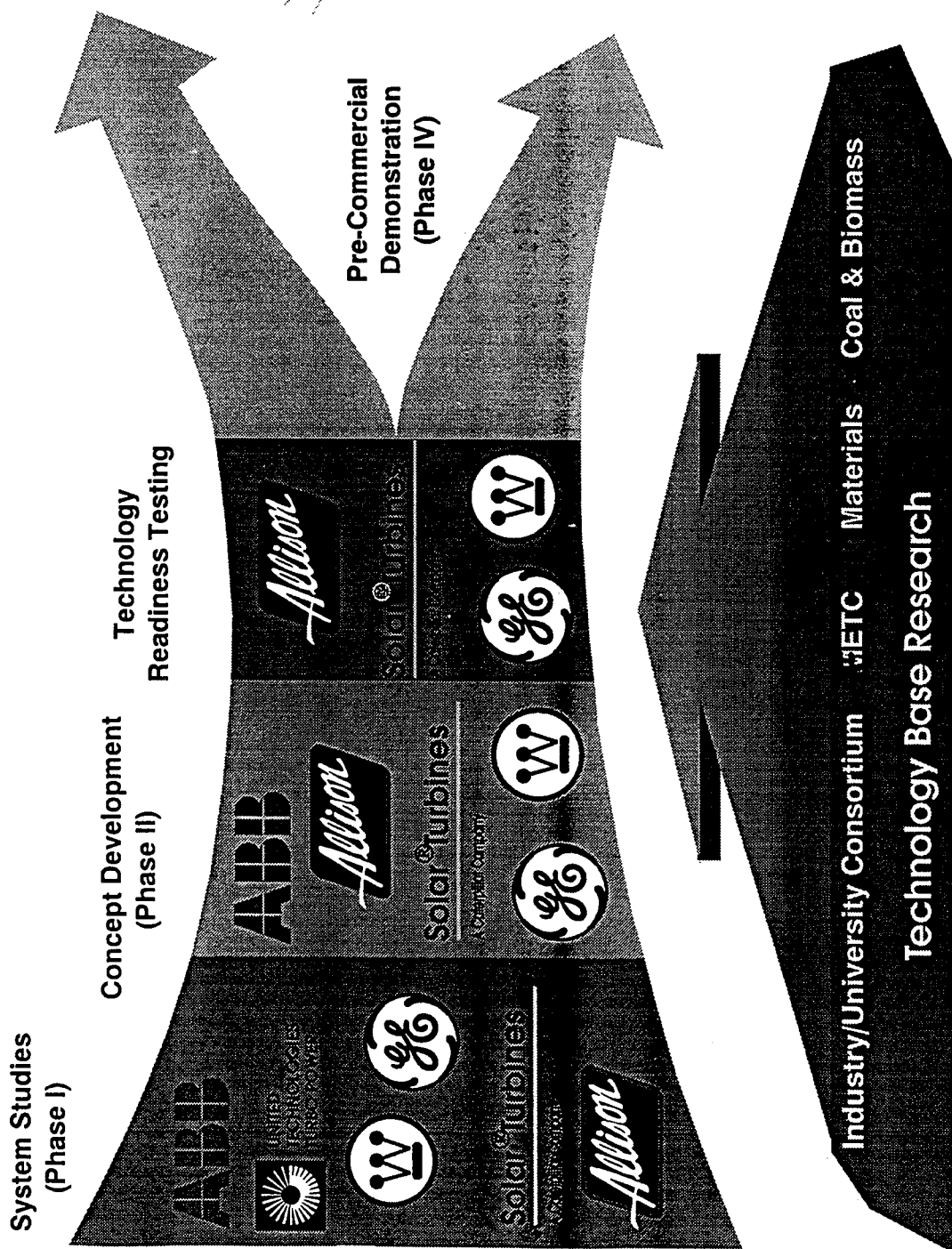
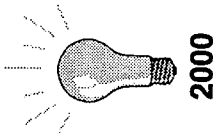
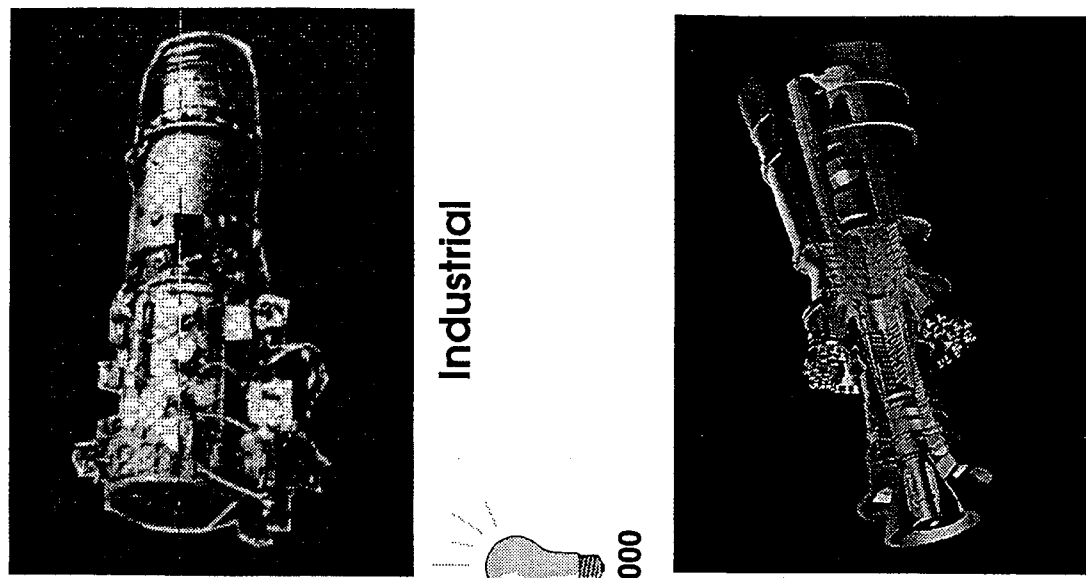
Objective: ATS Program

By 2000, develop ATS for utility and industrial applications that are:

- Ultra-high efficiency: > 60% for utility scale systems
15% improvement for industrial system
- Super-clean: $\text{NO}_x < 8 \text{ ppm}$
- Cost of electricity 10% lower
- Fuel flexible: Gas primary focus

Leapfrog in Turbine Performance

The ATS Program Today



Phases 3 & 4

Utility (>55 Kg/s ISO Airflow)

Develop and demonstrate a natural-gas-fired ATS for base-load, utility-scale power generation.

Requirements:

- System efficiency over 60%, LHV
- NO_x less than 9 ppmvd at 15% O₂
- Busbar energy cost 10% less than today's advanced systems
- Adaptable to coal or biomass fuels
- RAM equivalent to today's advanced systems
- Available for market in 2000

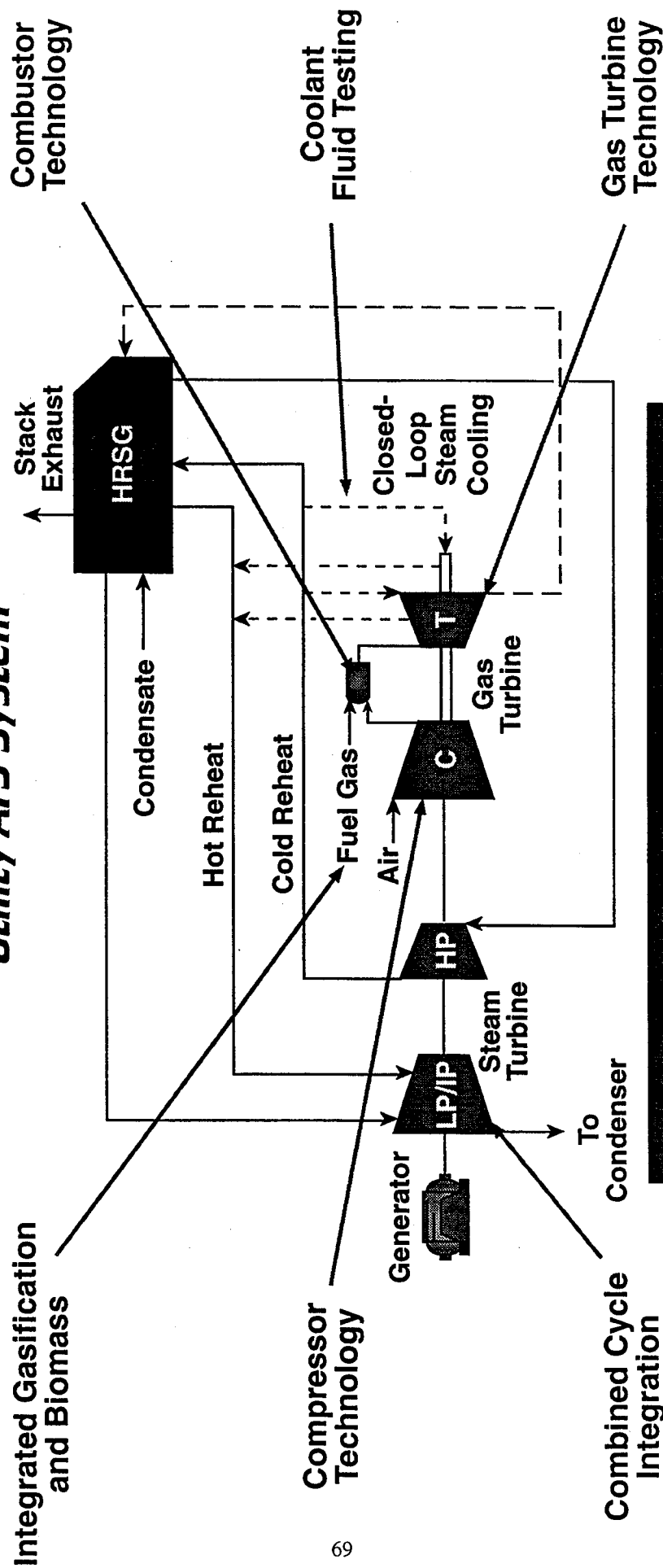
Status-Natural Gas Initiative

- General Electric and Westinghouse have completed utility scale ATS product conceptual design and development
- Allison and Solar have completed industrial scale ATS product conceptual design and development under EE Funding
- General Electric and Westinghouse have completed first year of Phase 3

Utility Advanced Gas Turbine Systems

Technology Validation and Testing of Critical Components

Utility ATS System



Combined Cycle With Closed-Loop Steam Cooling

- General Electric Company
- Westinghouse Electric Corporation
- Asea Brown Boveri

Status-Ultra High Efficiency Program

Technology Base Development

FETC-MGN:Inhouse R & D

- Completed cooperative efforts with gas turbine manufacturers for control of combustion instability, testing of novel, low emissions combustors, and identification of mechanisms which cause combustion oscillations
- Will investigate catalytic and humid-air combustion mechanisms, and instabilities related to dual-fuel systems

Advanced Gas Turbine Systems Research (AGTSR) Program

AGTSR "Triad"

- Industry/University Research Consortium:
 - 83 performing member institutions
 - 36 states represented
 - 4 RFP's announced
 - 7 gas turbine manufacturers
- Education program
 - Undergraduate research fellowships
 - Industrial internships
 - Faculty internship
 - Short course
- Workshops & seminars
 - 7 to-date
 - Heat Transfer workshop - February 12-14, 1997
 - Combustion workshop - March 5-7, 1997

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Advanced Gas Turbine Systems Research (AGTSR) Program

Points of Contact:

IRB:	AlliedSignal - Dave Winstanley (602) 231-1556 Allison - Sy Ali (317) 230-6864 GE - Harold Miller (518) 385-7779/1660 Solar Turbines - George Padgett (619) 544-5708 TurboPower (UT) - Bill Day (203) 343-2006 Westinghouse - Ihor Diakunchak (407) 281-5115 Parker Hannifin - Curt Scheuerman (216) 531-3000, ext. 2450
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Advanced Gas Turbine Systems Research (AGTSR) Program

Request for Proposals (RFP) status:

- 4 to-date:
 - 10 projects in FY 93
 - 13 projects in FY 94
 - 9 in FY 95
 - 9 in FY 96 *

* If approved, 41 projects underway: 14 in combustion, 12 in heat transfer, 7 in aerodynamics, 8 in Materials

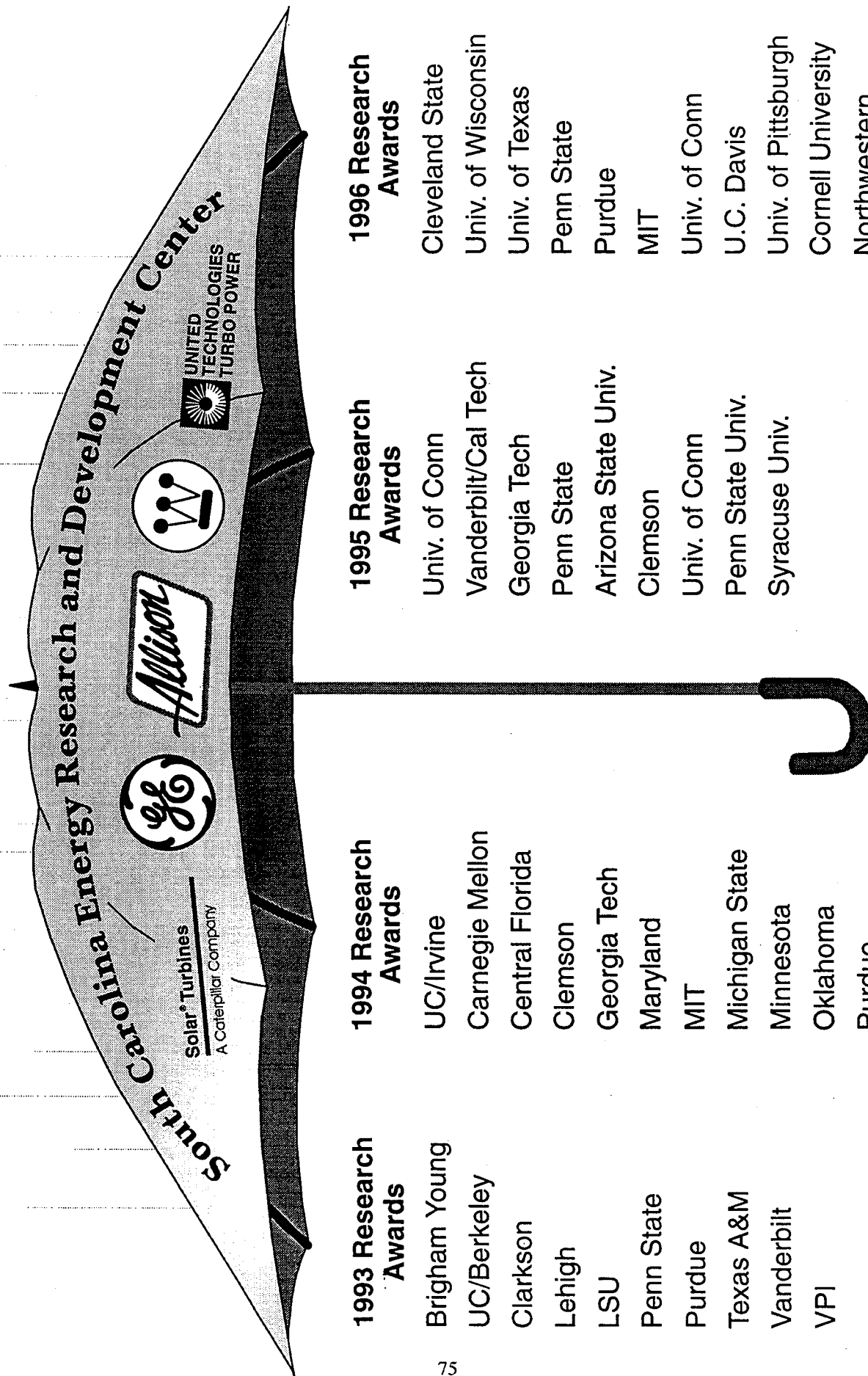
Status-Ultra High Efficiency Program Technology Base Development (continued)

South Carolina Energy Research and Development Center

Under the direction of the South Carolina Energy and Research Development Center (SCERDC), universities under contract will continue applied research specific to the needs of major ATS developers in combustion, aerodynamics, materials, and heat transfer.

- The research in combustion is focused on modeling, lean pre-mixed combustion, instability and active control, and advanced sensors.
- The research in materials focuses on thermal barrier coatings and steam effects on turbine blades.
- The research on aerodynamics focuses on computational modeling for designing improved performance compressors and turbines, and experimental investigations of three-dimensional flow.
- The research in heat transfer focuses on internal heat transfer enhancement, rotational influence, film cooling, sensors, heat transfer characteristics of steam and air, heat pipe vane stators, rotor disk cooling, and mist cooling.
- Workshops for technical exchange in the combustion and heat transfer, and materials areas.
- Internships of university students and faculty at the industrial review board facilities

Industry/University Consortium



1993 Research Awards

Brigham Young
UC/Berkeley
Clarkson
Lehigh
LSU
Penn State
Purdue
Texas A&M
Vanderbilt
VPI

1994 Research Awards

UC/Irvine
Carnegie Mellon
Central Florida
Clemson
Georgia Tech
Maryland
MIT
Michigan State
Minnesota
Oklahoma
Purdue
Wyoming

1995 Research Awards

Univ. of Conn
Vanderbilt/Cal Tech
Georgia Tech
Penn State
Arizona State Univ.
Clemson
Univ. of Conn
Penn State Univ.
Syracuse Univ.

1996 Research Awards

Cleveland State
Univ. of Wisconsin
Univ. of Texas
Penn State
Purdue
MIT
Univ. of Conn
U.C. Davis
Univ. of Pittsburgh
Cornell University
Northwestern

Status-Ultra High Efficiency Program Technology Base Development (continued)

Combustion Barrier Issues

- A gas turbine combustor for IGCC applications has been designed tested. Combustor can reduce NO_x emissions significantly
- Humid-air turbine combustion barrier issues will be resolved

ATS Materials/Manufacturing Element

Oak Ridge National Laboratory

- Develop materials/manufacturing technologies for the Gas Turbine Industry at large.
- Provide direct support on materials activities to the ATS prime contractors.
- Co-funded by the Office of Fossil Energy (FE) via METC and the Office of Energy Efficiency and Renewable Energy (EE).
- Current activities include Single Crystal Manufacturing Technology (FE), Coatings and Process Development (EE), Materials Characterization (EE & FE), and Technology Information Exchange (FE & EE).
- Under consideration for future activities in the Materials/Manufacturing Element are turbine airfoil development, ceramic materials development, and catalytic combustor materials.

ABB Advanced Gas Turbine System

Phase 2 Status

- Status: System defined, evaluating critical components
- Incorporate turbine cooling advances (turbulators and advanced wall cooling features)
- Utilize single crystal blading for the air-cooled rotor blade stages
- Integrate thermal barrier coatings (TBC) with turbine cooling advances and single crystal blading to reduce air foil cooling air needs
- Steam cooling of the GT-24 turbine vanes
- The turbine exhaust temperature is increased further to improve combined cycle performance